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ORIGINAL PAPER

Forest fire risk assessment in parts of Northeast India using geospatial tools

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Abstract: Forest fire is a major cause of changes in forest structure and function. Among various floristic regions, the northeast region of India suffers maximum from the fires due to age-old practice of shifting cultivation and spread of fires from jhum fields. For proper mitigation and management, an early warning of forest fires through risk modeling is required. The study results demonstrate the potential use of remote sensing and Geographic Information System (GIS) in identifying forest fire prone areas in Manipur, southeastern part of Northeast India. Land use land cover (LULC), vegetation type, Digital elevation model (DEM), slope, aspect and proximity to roads and settlements, factors that influence the behavior of fire, were used to model the forest fire risk zones. Each class of the layers was given weight according to their fire inducing capability and their sensitivity to fire. Weighted sum modeling and ISODATA clustering was used to classify the fire zones. To validate the results, Along Track Scanning Radiometer (ATSR), the historical fire hotspots data was used to check the occurrence points and modeled forest fire locations. The forest risk zone map has 55–63% of agreement with ATSR dataset.

Keywords: ATSR; forest fire; modeling; risk zonation; weights; Manipur

Introduction

Information on the distribution of forest fire risk zones is essential for the effective and sound decision making process in the forest management (Hussin et al. 2008). Forest fire risk evaluation is a critical part of fire prevention, since pre-fire planning resources require objective tools to monitor when and where a fire is more prone to occur, or when will it have more negative effects (Chuvieco et al. 2010). Forest fire modeling involves the risk assessment and evaluation. The term "risk" is used to describe the probability that a fire might start, as affected by the nature and incidence of causative agents (Keane et al. 2010). At global scale, fire risk evaluation for the proper management of forest was done through different techniques like logistic regression and linear regression analysis (Chuvieco et al. 2010), algorithm like fire risk assessment algorithm (FIRA) based on normalized brightness and wetness indices, fire risk simulation model FARSITE (Mbow et al. 2004, www.fire.org), classification and regression trees (CART) a statistical approach for modeling fire occurrence (Lozano et al. 2008), and artificial neural network (Maeda et al,2009), as well as FIRE Hazard and Risk Model (FIREHARM) that computes common measures of fire behavior, fire danger, fire effects to spatially portray fire hazard over space (Keane et al. 2010) and many others. Models were used such as locally criterion-based analysis (Jaiswal et al. 2002), multi parametric weighted index modeling (Roy 2003), multi criteria spatial analysis (Rawat 2003), forest fire likelihood modeling (Srivastava 2006) and many others. Accurate and updated information regarding forest and forest fires could play vital and effective role in forest management programmes (Kunwar et al. 2003). Monitoring these fires became easier with the availability of satellite data obtained with high temporal repeatability, spectral variability and wide spatial coverage (Giriraj et al. 2010).

Northeast part of India, which suffers maximum from the fires due to the age-old practice of shifting cultivation (*jhum*) and spreads fires from *jhum* fields, need immediate attention with respect to forest fire as well as developing an early warning system. Such areas require stratification in terms of vulnerability of vegetation types of forest, so as to ensure greater attention of location. This study attempts to utilize the capabilities of remote sensing and GIS to detect forest fire prone areas through forest fire risk modeling in Manipur. The main objective is to develop rank weighted geographic model of fire risk analysis to detect

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fire risk areas. Most of the fire models discussed earlier are complex and require many variables. They are difficult for the local stakeholders of Northeast India to understand, and collecting such detailed information for Manipur is very challenging in light of least infrastructure availability. Therefore, a user-friendly model for forest fire is developed based on few but key and easily available indicator variables.

Materials and methodology

Study area

The study area includes a "soft-state" on the Northeastern border between India and Myanmar, as well as Manipur with a total geographical area of 22 327 km^2, of which 90% is undulating terrain, largely characterized by dense forests and inaccessible terrain. The state is located between 23° 83′–25° 68′ N and 93°03′–94°78′ E at the Northeast extreme of India (Fig. 1), nestling at an altitude of about 790 m. The valley is surrounded by hills, claims 10% of the total area and is inhabited by 61.55% of the total population (2001), while the remaining 38.45% occupies hilly districts. The length of international border shared by the state is 352 km accounting for 41.21% of the total length of the border (www.manenvis.nic.in).

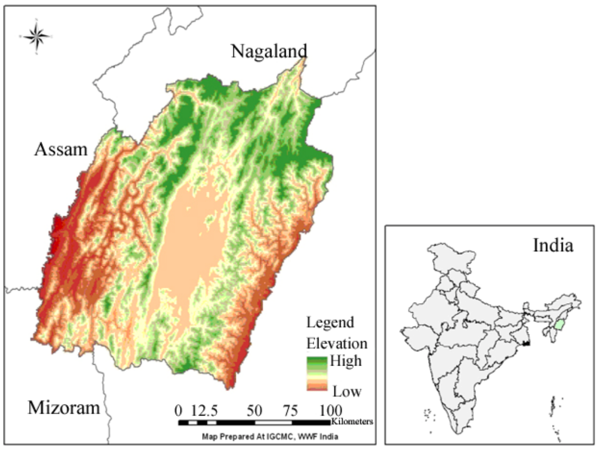

Fig. 1 Location of the study area

The climate of Manipur can be classified as follows: (1) Temperate prevailing in the higher altitude of hill where temperate fruits and vegetables can be grown throughout the year; (2) Sub-tropical prevailing in the lower attitudes hills and central valley plain where winter lasts from November to February and rainy season from May to September; (3) Tropical prevailing in Jiri plains and foothills during March.

There are four types of forests: (1) Tropical semi-evergreen forests found in western Manipur hills in the Barak drainage system that consist of timber species like *Adina cordifolia* (Haldi), *Acer niveum* (Sundi), *Cedrella toona* (Toon), *Lagrostomia flosregina* (Jarul), *Phoebe* spp. (Bonsum), good quality *Calamus* spp. (Canes) and *Melocanna bambusoides* (Muli Bamboos); (2) Tropical moist deciduous forests situated along the Burma border in Manipur east hills and composed of *Tectona grandis* (Teak), *Melanorhoa usitata* (Khen) and *Cedrella toona* (Toon) trees; (3) Sub-tropical pine forests found in the northeastern part of Ukhrul district where *Pinus khasya* (uchal or khasi pine) interspersed with *Barringtonia* spp. (Oak) and *Aesculus indica* (Chestnuts); (4) Dry temperate forests found all over the Manipur valley that contain mixed forests of *Bombax malabaricum* (Semul), *Alnus nepalensis* (Pareng) and *Pinus Khasya* (Pine) (www.planningmanipur.gov.in).

Data used

The biophysical parameters (LULC and vegetation caver types), terrain parameters (DEM, slope and aspect) and human disturbance parameter (proximity to roads and settlements) were used in the forest fire modeling. IGCMC division of WWF-India provided softwares namely ERDAS Imagine 9.0 for satellite image processing and ArcGIS 9.2 for fire risk modeling and map preparation.

The Manipur State falls in the path and row 135/42 and 135/43 of Landsat data with a spatial resolution of 30 m and swath of 185 km. The orthorectified satellite data of Landsat ETM of March 2000 (135/43) and December 2001 (135/42) were downloaded from the website www.landsat.org, then the data were mosaiced and subsetted to obtain the study area. Digital Elevation Model (DEM) of the study area was downloaded from the Shuttle Radar Topography Mission (SRTM) website http://srtm.csi.cgiar.org/. Slope and aspect was derived from DEM. The vegetation type data was downloaded from Global Land Cover Facility website to know about the distribution of Deciduous Broadleaf forests, Evergreen Broadleaf forests, Evergreen Needle leaved forests and mixed forest, grassland and woodland present in the study area.

Image processing

The Landsat image was geometrically and radiometrically corrected. The LULC map was, then, prepared by unsupervised classification using ISODATA clustering analysis. The interactive editing mode was used to merge spectral classes and delineate some of the information classes, which were intermixed due to less spectral separability. Separate AOIs were prepared for water body, riverbed and built-up to edit the pixels on the classified map. IGCMC division of WWF, INDIA provided the road network and settlement maps of Manipur. These were georectified and digitized using ArcGIS. The Euclidean distance for road and settlement data was generated. It helped in incorporating the neighborhood impacts of the forest fires.

Fire risk modeling

Modeling was conducted by using ArcGIS 9.0 software by computing the factors responsible for influencing the fire behavior. An integrated analysis was performed by combining the inputs and multiplying them with their specified weight, where a weight is a value assigned to variable that indicate the importance rela-

tive to variable. The variable with higher degree of influence on the fire risk was given the higher weightage. Subjective weights were given to the different classes according to their sensitivity to fire or their fire-inducing capability. Thereby, the forest fire risk zones were delineated. The equation used in GIS environment for the fire risk modeling and for mapping the fire risk areas is:

$$FR = V_{i=1-6} + L_{j=1-12} + H_{k=1-10} + R_{l=1-10} + S_{m=1-3} + A_{n=1-8} \quad (1)$$

where, *FR* is the numerical index of fire risk, *V* the vegetation variable (with 1–6 classes), *L* the land use/land cover variable (with 10 classes), *H* indicates proximity to human habitation (with 1–10 classes), *R* the road factor (with 1–12 classes) and *S* indicates slope factor (with 1–3 classes) and *A* is the aspect (with 1-8 classes). The subscripts *i*, *j*, *k*, *l, m, n* indicate subclasses based on importance in determining the fire risk. Weightages given to parameters involved in the fire risk modeling are given in Table 1.

Table 1. Summary of weights assigned to each class for forest fire risk modeling

	Variables	Classes	Weights	Fire Sensitivity
Bio-physical Parameter	Vegetation type	Grassland	10	Very High
		Evergreen Needle leaf Forest	9	High
		Mixed Forest	9	High
		Woodland	9	High
		Deciduous Broadleaf Forest	6	Moderate
		Evergreen Broadleaf Forest	6	Moderate
	Land Use/Land Cover	Open Forest	10	Very High
		Scrub Forest	8	High
		Dense Forest	6	Moderate
		Open / Degraded Land	6	Moderate
		Built Up	4	Low
Terrain parameter	Slope (in degrees) (Demek, 1972; Bell, 1998)	0-5 (Plain/ gently inclined)	2	Low
		5-15 (Strongly inclined)	5	Moderate
		>15 (Steep)	10	High
	Aspect	North	2	Low
		North East, North West	3	Low
		East	6	Moderate
		West	8	High
		South East, South West	9	High
		South	10	Very High
Human Disturbances parameter	Buffer of Towns (in km)	0-2	10	Very High
		2-4	9	High
		4-6	8	High
		6-8	7	Moderate
		8-10	6	Moderate
		10-12	5	Moderate
		12-14	4	Low
		14-16	3	Low
		16-18	2	Low
		>18	1	Very Low
	Buffer of Roads (in km)	0-2	10	Very High
		2-4	9	High
		4-6	8	High
		6-8	7	Moderate
		8-10	6	Moderate
		10-12	5	Moderate
		12-14	4	Low
		14-16	3	Low
		16-18	2	Low
		>18	1	Very Low

Results and discussion

Forest fire risk map

The factors influencing the forest fire behavior in an area were given with relative weights accordingly. To obtain the forest fire risk map using forest fire modeling, the LULC map (Fig. 2), vegetation type map (Fig. 3), slope map (Fig. 4), aspect map (Fig. 5) and Euclidean distance to town and roads (Fig. 6 and Fig. 7) were prepared. LULC map comprised of 12 classes (dense forest, open forest, scrub forest, agriculture/fallow land, open/degraded land, river/water body, rocky exposure, swampy land, floating land, built up, cloud and shadow). Spatial patterns of land cover revealed that the degraded patches were observed in the dense forested areas. The selection of the bands for classification was based on the spectral profile analysis. Vegetation type data contained spatial distribution of Deciduous Broadleaf forests, Ever-

green Broadleaf forests, Evergreen Needle leaved forests, mixed forest, grassland and woodland classes.

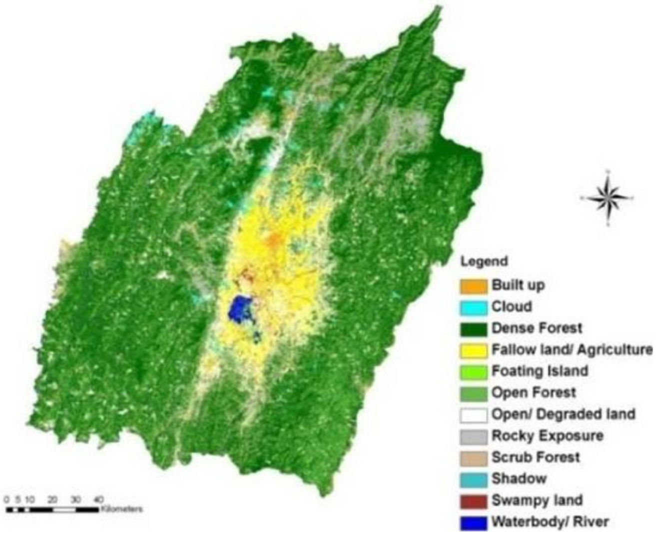

Fig. 2 LULC map of Manipur, 2001

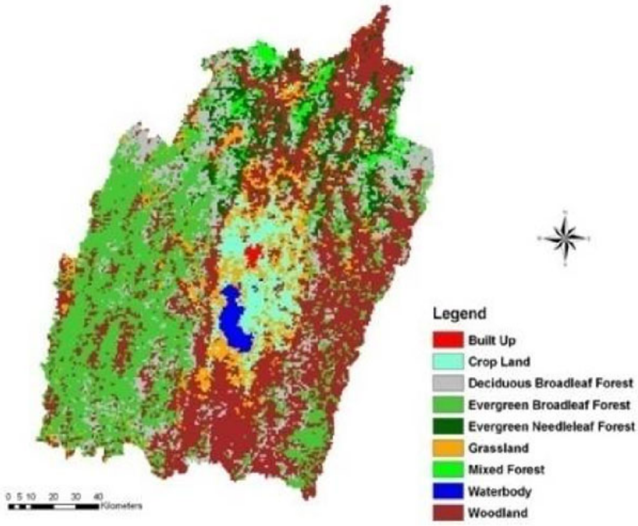

Fig. 3 Vegetation type of Manipur

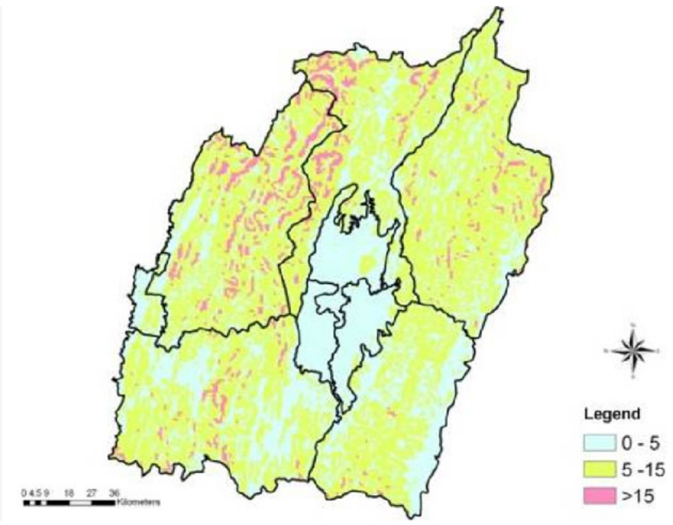

Fig. 4 Slope map

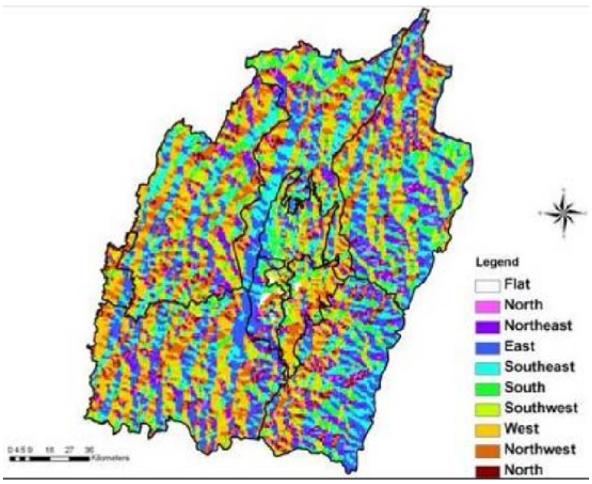

Fig. 5 Aspect map

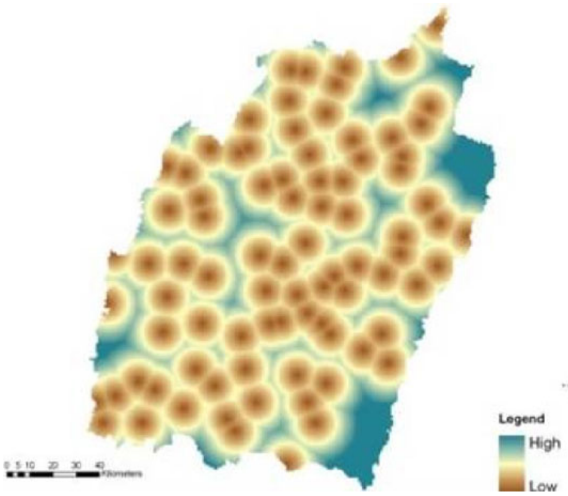

Fig. 6 Euclidean distance of town

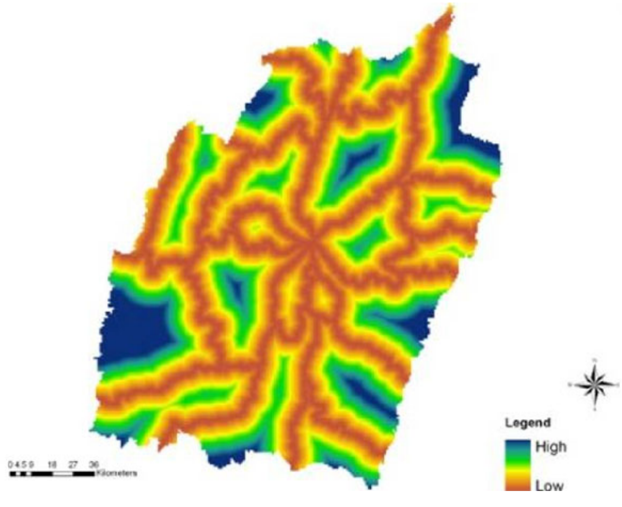

Fig. 7 Euclidean distance of road

The output of the weighted sum approach was a forest fire risk map of Manipur (Fig. 8). The final map contains pixel values ranging from 10 to 60. ISODATA clustering technique was used to group these pixel values into risk categories, i.e. very low, low, moderate, high and very high. The very low risk category denotes that the areas with low chances of forest fire are less susceptible comparative to high and very high risk areas, which are having the most favorable factors for forest fire. The area statistics of forest fire risk distribution is shown in Table 2.

Table 2. Forest fire risk area

Categories	Area (km^2)	Area (%)
Very low	4135.75	18.52
Low	5697.23	25.52
Moderate	4304.98	19.28
High	4992.07	22.36
Very high	3196.98	14.32

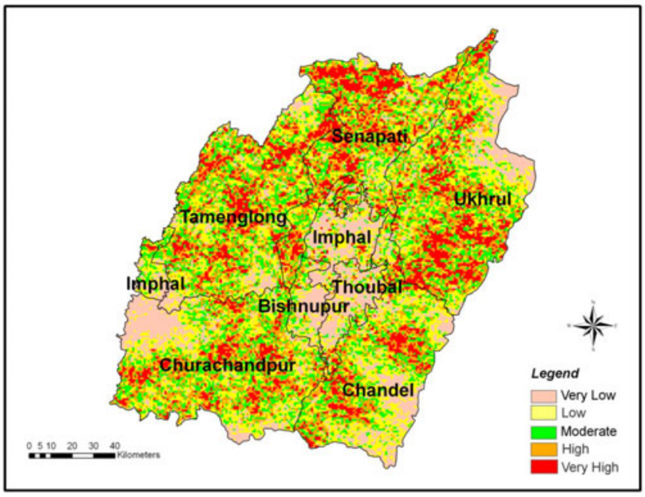

Fig. 8 Forest Fire Risk Map

District wise analysis

Manipur state is predominantly an agricultural economy. The cultivators and agricultural laborers comprise of over 57% of the state's working population. The four valley districts (Imphal East, Imphal West, Thoubal and Bishnupur) cover 10.02% of total geographical area; include 73.18% of total agricultural land. Most of the populations reside in these districts, 61.54% of the total population (2001) is in the valley, while 38.46% in the hill districts (http://manipur.nic.in/). The district wise analysis (Table 3) shows that Thoubal, Bishnupur and Imphal (East-West) have least chance for forest fire, because there is not much forest area situated in the plains of Manipur. Also, the occurrence of Loktak Lake, which is a largest fresh water lake in the Northeast India, with the length of 48 km from Imphal and falls in Bishnupur.

Whereas, Senapati and Ukhrul districts are the most vulnerable to forest fire with the highest area for very high risk zones of approximately 850 km^2 and 800 km^2, respectively. The presence of open forest, scrub forest, woodland and grassland in these districts and Sub-tropical pine forests found in the north-eastern part of Ukhrul district, where uchal or khasi pine (*Pinus khasya*) interspersed with oak and chestnuts make them most exposed to the chances of natural as well as manmade forest fires. The local people living in the hill districts are dependent on forest resources and practice shifting cultivation. This land use practice involves slashing the vegetation, burning the dried slash before the onset of the monsoon, raising a mixture of crops on a temporarily nutrient enriched soil for a year or two, and allowing the soil to fallow in the plot with regrowth of natural vegetation (Ranjan et al. 1999).

Also, slope and aspect variable are the structural factors for detecting fire risk. Moderate to steep slopes are present in the hill districts namely Senapati, Ukhrul, Chandel, Churachanpur and Tamenglong whereas flat slopes are in the remaining valley districts. Lower degree risk areas are with flat slopes, whereas higher risky areas are those with steep slopes and southern aspect because of the presence of warmer conditions.

Table 3. District wise area statistics of forest fire risk zones in sq.km

Categories	Chandel	Churachandpur	Imphal	Senapati	Tamenglong	Thoubal	Ukhrul	Bishnupur
Very low	706.61	871.51	640.07	364.51	483.13	444.07	661.77	248.80
Low	1011.82	1264.95	392.72	767.36	1121.75	175.02	1127.54	123.67
Moderate	611.86	962.64	193.11	716.01	956.85	88.96	902.61	67.98
High	628.50	1121.75	101.98	1053.04	1073.29	65.82	1113.07	33.27
Very high	358.01	488.19	68.71	851.26	725.41	37.61	808.59	10.13

Validation of the study

The fire data were obtained from ATSR World Fire Atlas (WFA) (http://dup.esrin.esa.int/ionia/wfa_data/wfa.php) for the years 1995–2004 in ASCII format (American Standard code for Information Interchange). The data were converted to shapefile and the projection was set as that of the study area. The study area was clipped from the fire data, which included the time, date, longitude and latitude of the fire hot spots. Using the zonal statistics in ArcGIS, it was checked how many fire points fall in the predicted forest fire risk categories (Table 4). Statistical filtering [(Median Filter (3×3) and Mode Filter (3×3)] were also run in the result so as to avoid the noise in the predicted image and to group them in their respective classes. It was found that out of

136 points, 55 points were in the high and very high categories of the risk map. The forest risk zone map was with 55−63% of agreement with ATSR dataset. Around 10% points were under the very low and around 25% were under low category, which is very likely with the modeling exercise (the weights are defined using interactive advices). While investigating the distribution of the validation points it was found that around 10% of the points fall under the cropland and unclassified areas which are not part of forest fire. Around 30% points were under the evergreen broadleaf forest and 12% under deciduous broadleaf forest, which have relatively less sensitivity towards forest fire incidence. Similarly while visualizing the distribution of forest fire points on the LULC cover map, it was found that around 48% points are distributed over dense forest and open/degrade land, which are less sensitive to forest fire. Such a skewed distribution of validation points is reflected in the agreement with the ATSR dataset. The evaluation of fire risk map also indicates higher chances of forest fire in the woodland and mixed forest, which shows around 100% agreement with the ATSR datasets. The developed risk map also indicates relatively lesser agreement with the distribution of grassland over the area, which is in contrast to the weight value allotted but has better agreement with the ATSR point distribution.

Table 4. Fire point distribution pattern

Categories	Unsupervised	Median filtered	Mode filtered
Unclassified data	-	1	3
Very low	17	14	16
Low	38	34	41
Moderate	26	34	21
High	32	38	31
Very High	23	15	24
Total	136	136	136

Conclusion

With the population increase in Northeastern states along with decrease in land-man ratio at an alarming rate, the *jhum* cultivation has lead to destruction of forest wealth. Loss of soil cover from denuded lands and siltation of reservoirs/rivers resulting in floods in the plains is other factors responsible for higher pressure on the forest (Paul et al. 2009). The forest fire is a key ecological process and also a threat to biodiversity. It can have unwelcome consequences, and can't be ignored.

Literatures reveal that the cycle of shifting cultivation in Northeastern states was reduced from 25–30 years to 2–3 years breaking the resilience of ecosystem and increasingly deteriorating. The traditional lifestyle, socio-culture value attached with *jhum* cultivation practice of food production by the local inhabitants, leads to non-adoption of any suggested alternatives. The forest cover is affected more by expansion of degraded patches due to *Jhum* cultivation. One important aspect for preventing future fire disasters is the level of awareness that can be gained by an early warning system. The study emphasizes on the importance of RS and GIS in identifying the forest fire prone areas, which needs immediate attention through information in terms of map. Study results can be used as a basic data to assist the fire management and prepare plans. With the help of the ATSR fire locations, we gained satisfactory validation results. However, the result needs to be verified at the ground level with field survey.

From the present study it can be concluded that this practice is very prominent mainly due to the increasing population pressure and their dependency on natural resources. The persistence of such a trend will result in the loss of the biodiversity, habitat fragmentation, affecting the wildlife etc., therefore, and the proper afforestation measures should be taken up. The problem can only be solved with the full cooperation of local people, by educating them about the hazardous consequences of forest fire, along with the establishment of latest fire fighting techniques and fire watchtowers in the vulnerable districts. Also, the development strategies should be made considering the ecological situations, socio-economic conditions and socio-cultural variations in Manipur.

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